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Hou et al.

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(54) **CMP POLISHING HEAD DESIGN FOR IMPROVING REMOVAL RATE UNIFORMITY**

(71) Applicant: **Taiwan Semiconductor Manufacturing Co., Ltd.**, Hsinchu (TW)

(72) Inventors: **Te-Chien Hou**, Kaohsiung (TW); **Ching-Hong Jiang**, Hsinchu (TW); **Kuo-Yin Lin**, Jhubei (TW); **Ming-Shiuan She**, Taoyuan (TW); **Shen-Nan Lee**, Jhudong Township (TW); **Teng-Chun Tsai**, Hsinchu (TW); **Yung-Cheng Lu**, Hsinchu (TW)

(73) Assignee: **TAIWAN SEMICONDUCTOR MANUFACTURING COMPANY, LTD.**, Hsin-Chu (TW)

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Related U.S. Application Data

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B24B 37/04	(2012.01)

(52) **U.S. Cl.**
CPC ***B24B 37/20*** (2013.01); ***B24B 37/042*** (2013.01); ***B24B 37/32*** (2013.01)

(58) **Field of Classification Search**
CPC B24B 37/005; B24B 37/042; B24B 37/20; B24B 37/30; B24B 37/32
USPC 451/287, 288, 289, 397, 398
See application file for complete search history.

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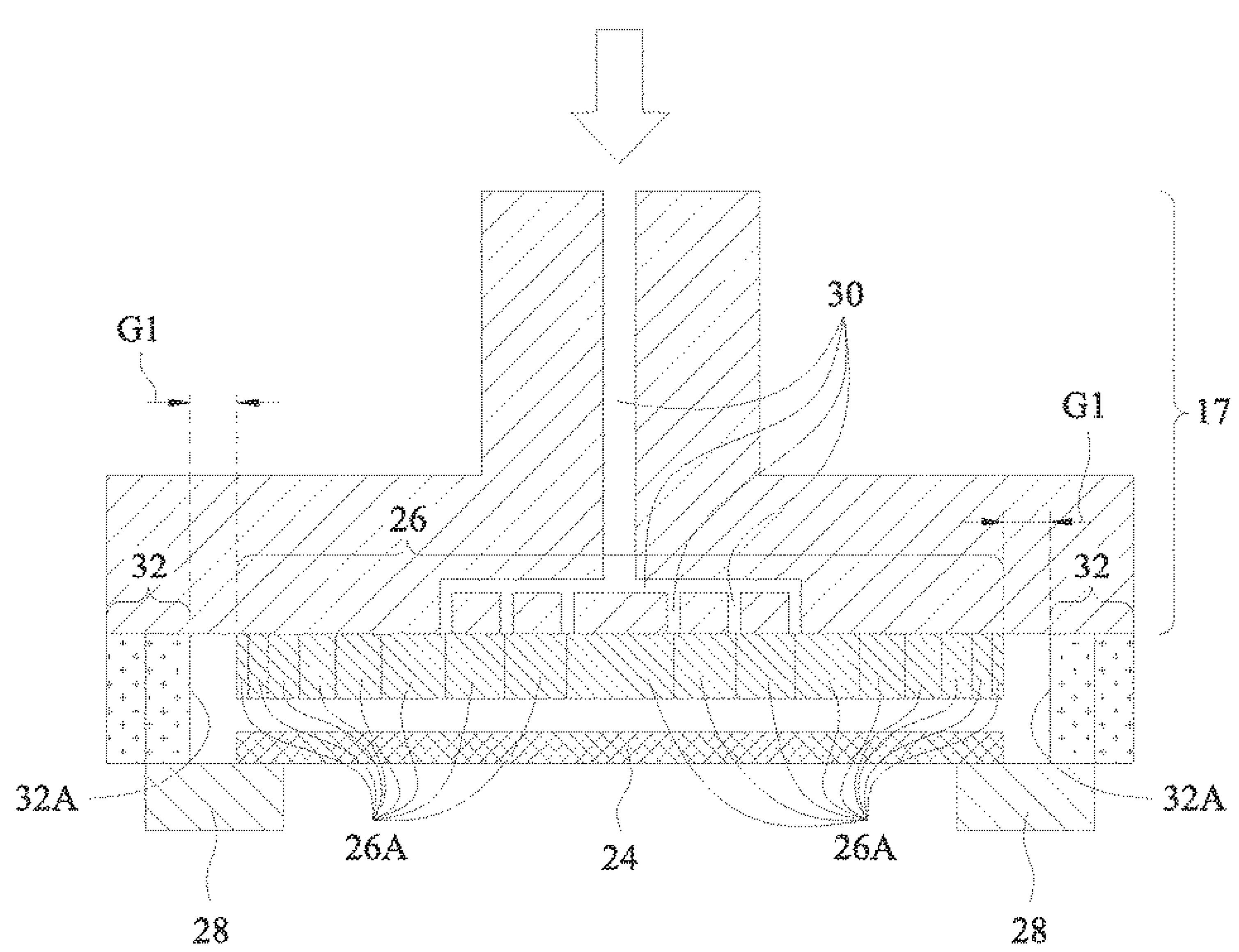
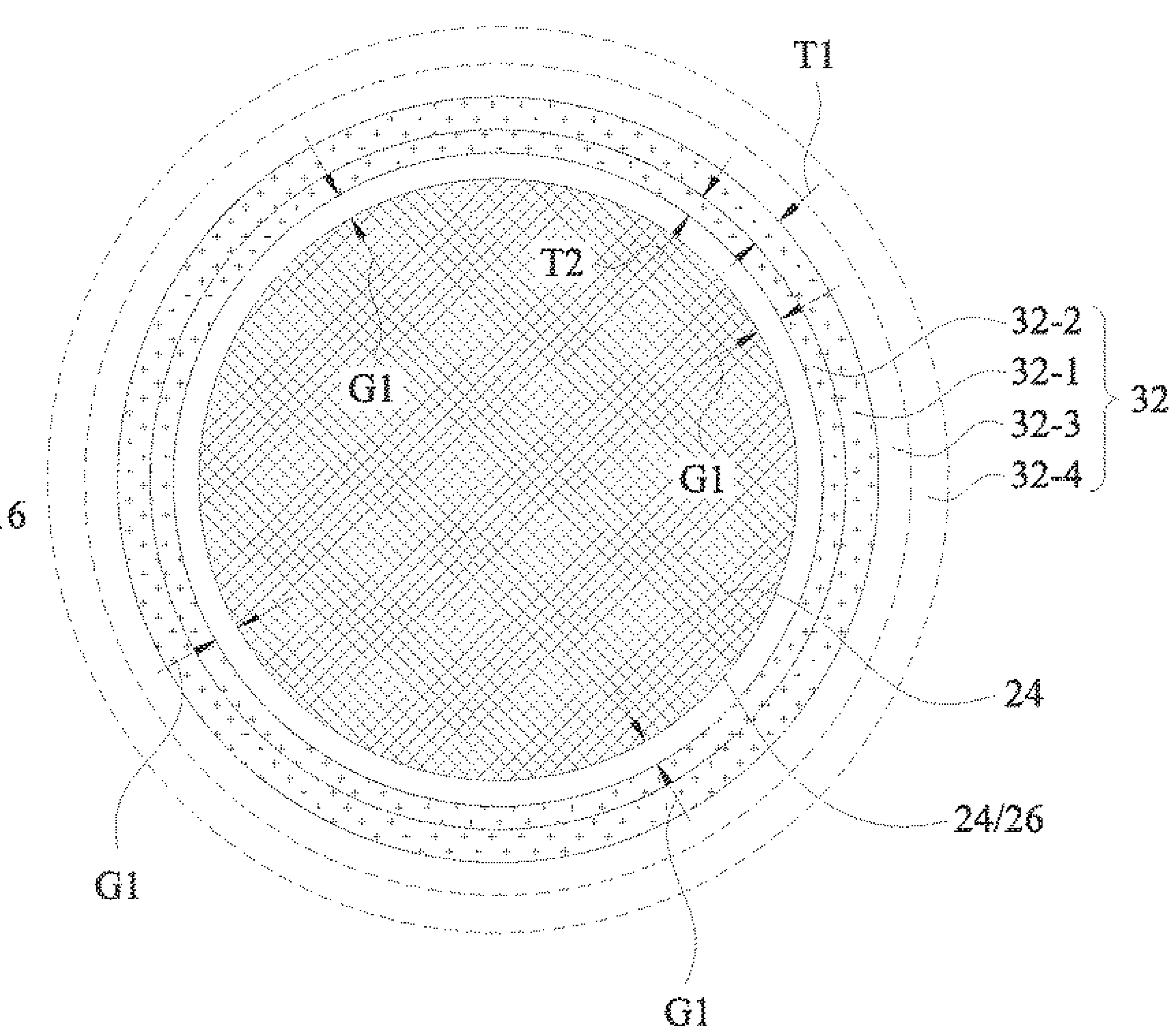
Primary Examiner — Eileen P Morgan
(74) *Attorney, Agent, or Firm* — Slater Matsil, LLP

(57) **ABSTRACT**

An apparatus for performing chemical mechanical polish on a wafer includes a polishing head that includes a retaining ring. The polishing head is configured to hold the wafer in the retaining ring. The retaining ring includes a first ring having a first hardness, and a second ring encircled by the first ring, wherein the second ring has a second hardness smaller than the first hardness.

20 Claims, 16 Drawing Sheets





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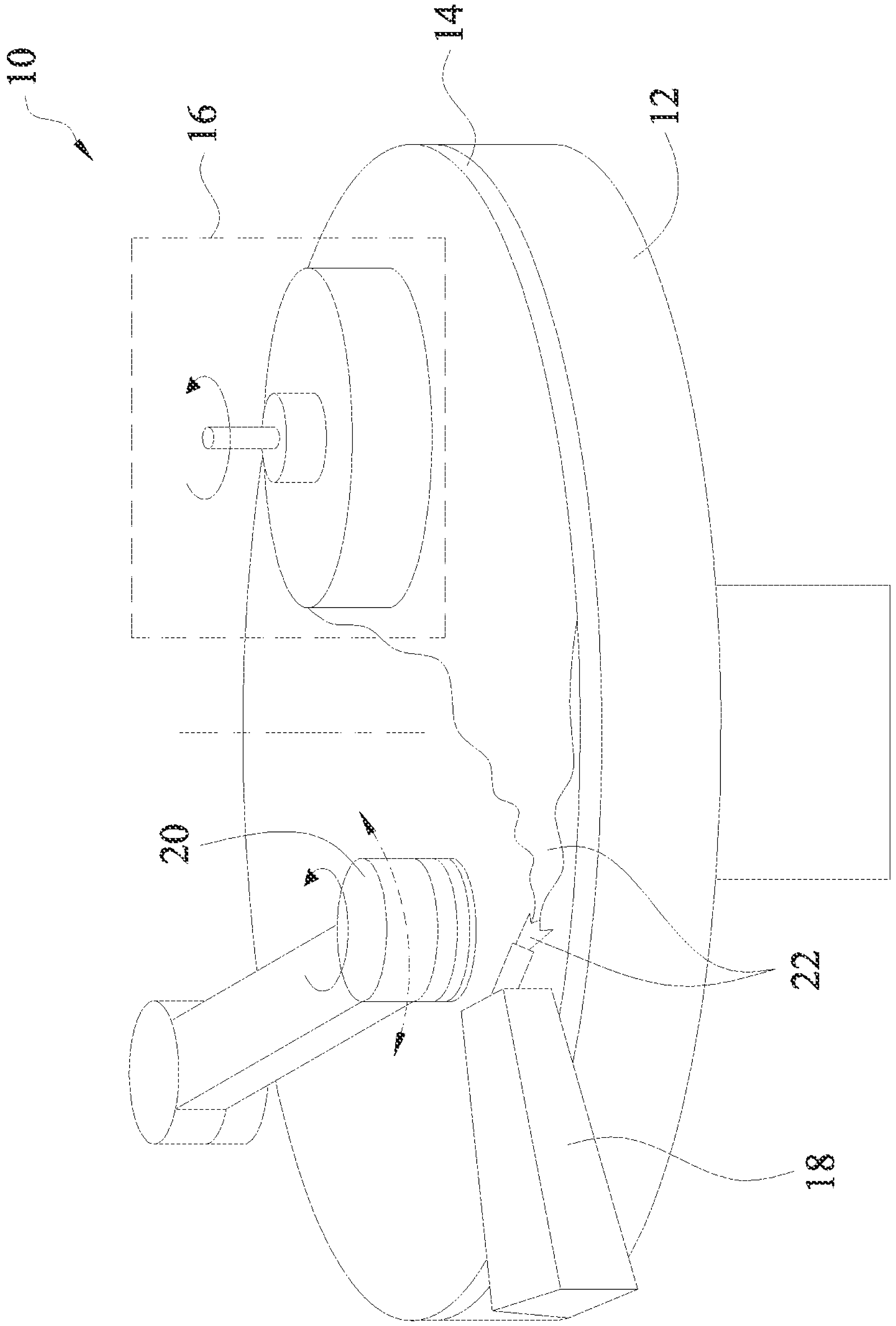


FIG. 1

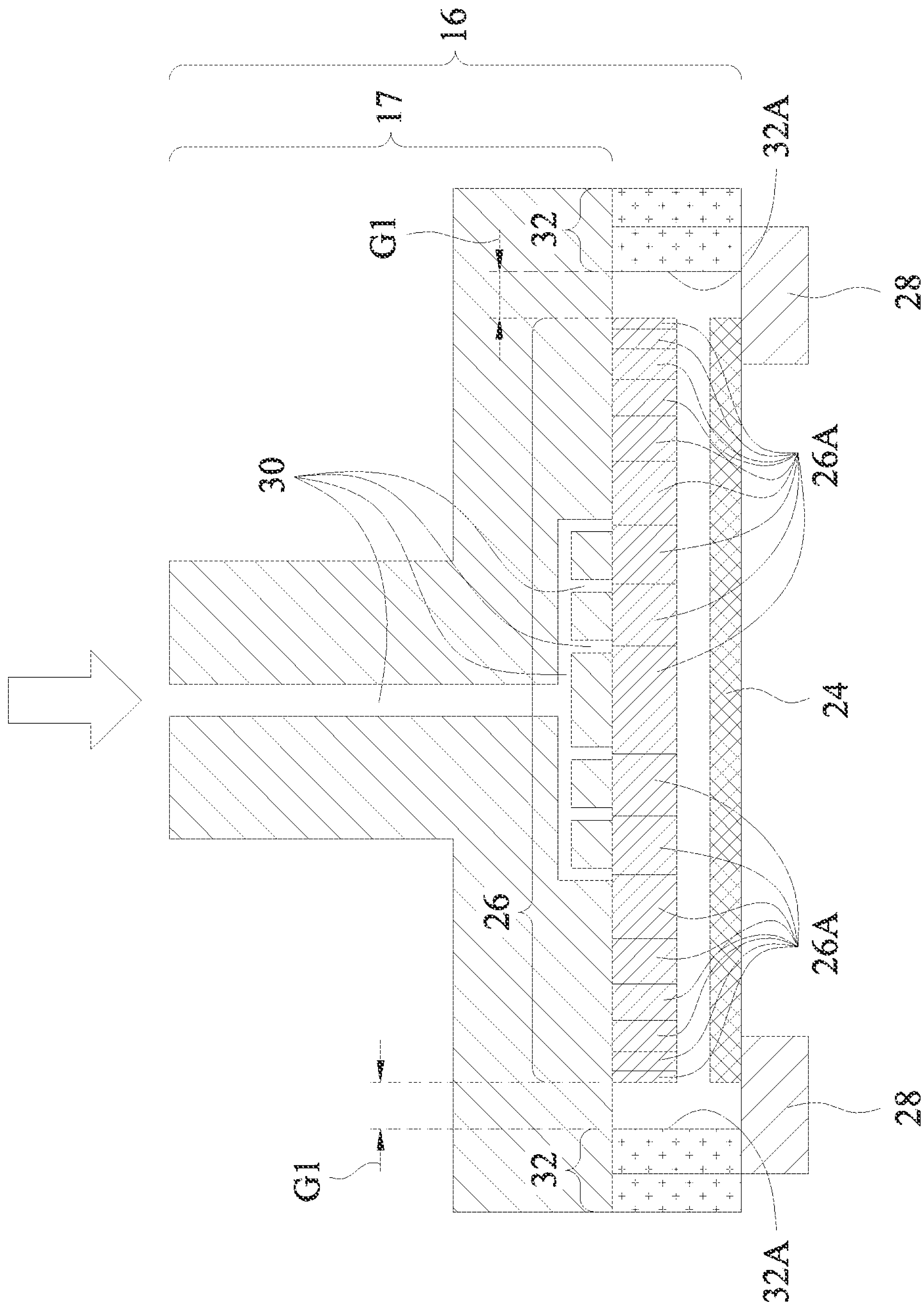


FIG. 2

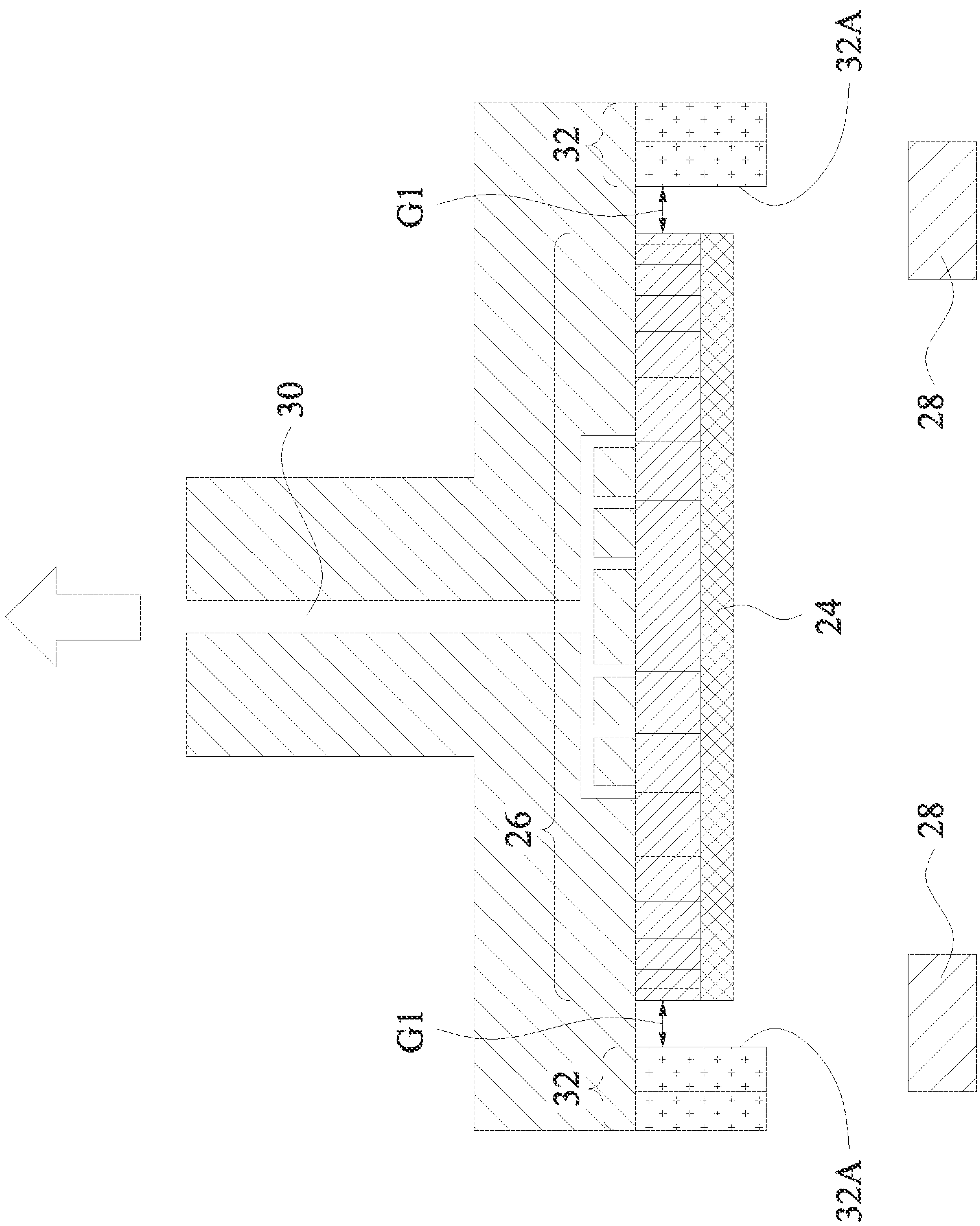


FIG. 3

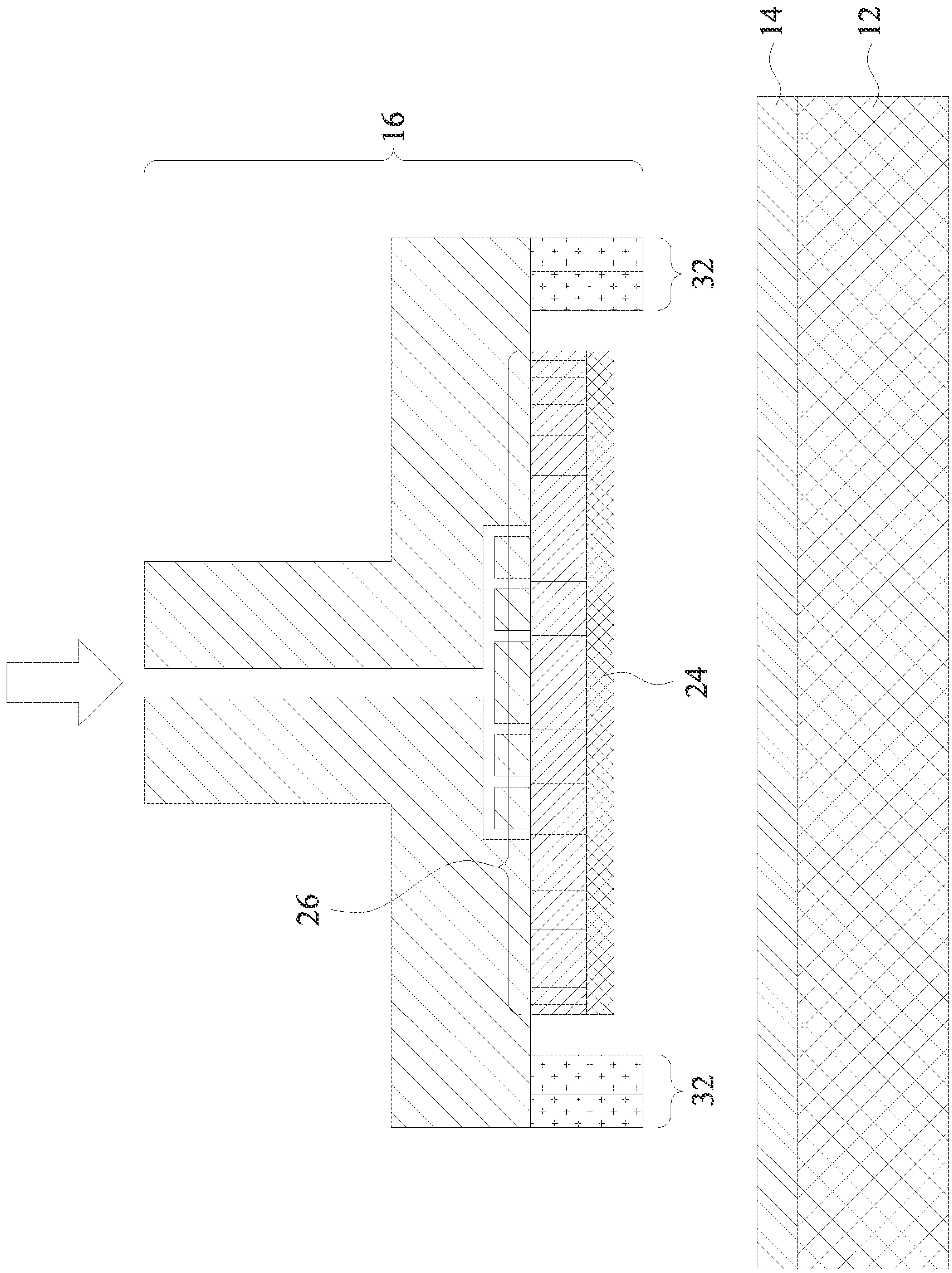


FIG. 4

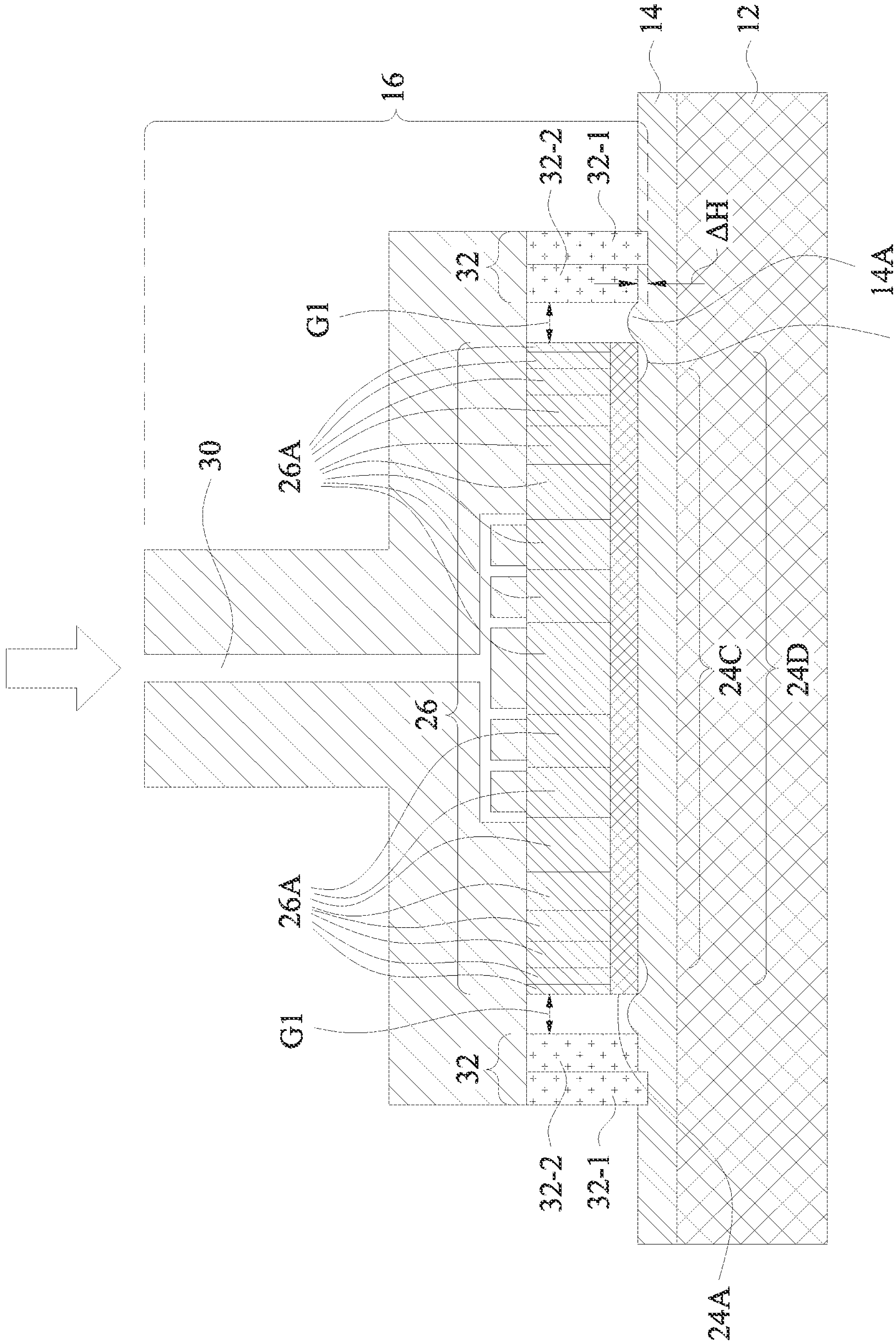

16
14
12
32-2
32-1
ΔH
32
14A
G1
35
30
26A
24C
24D
26
26A
G1
32
32-2
32-1
24A

FIG. 5

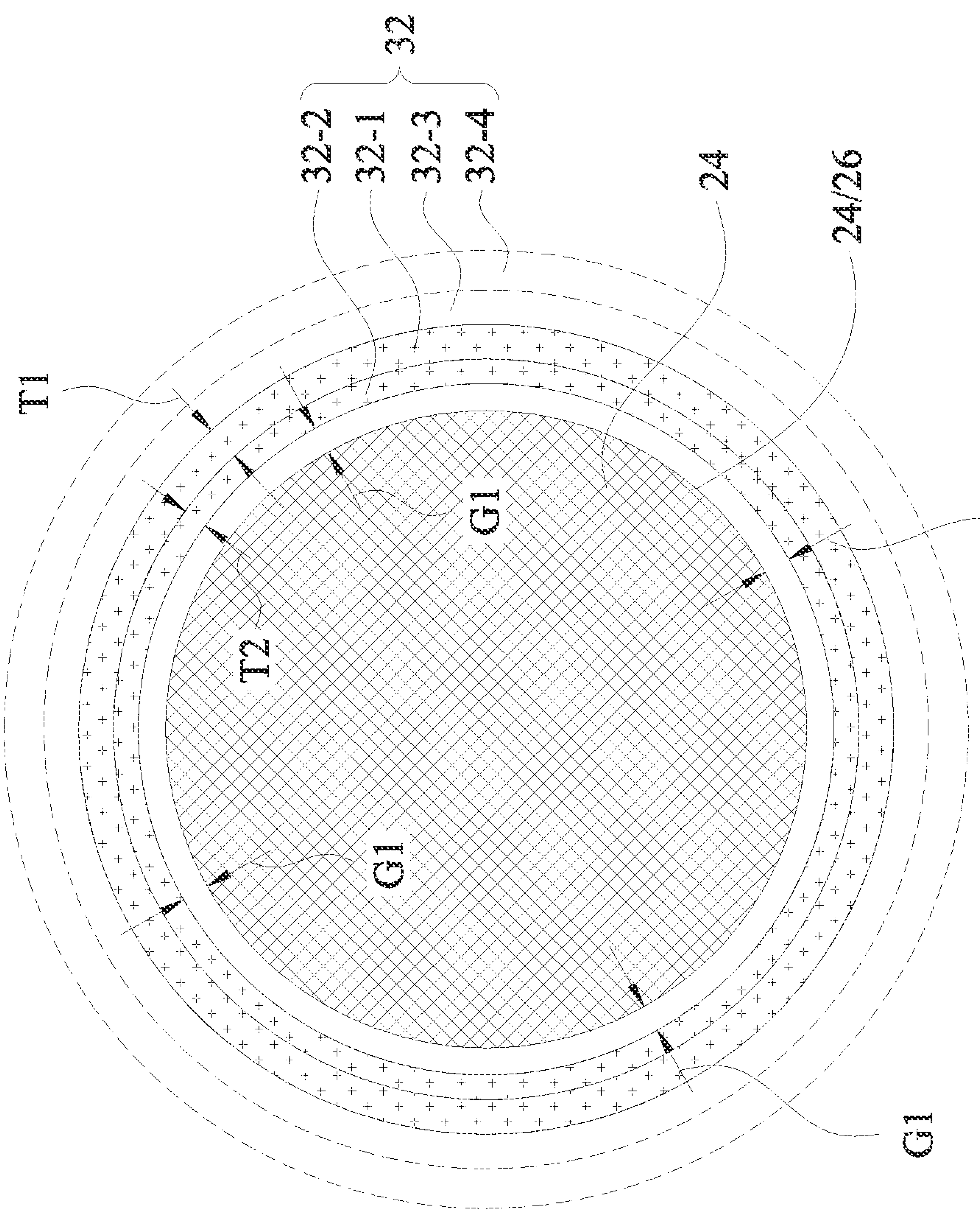


FIG. 6

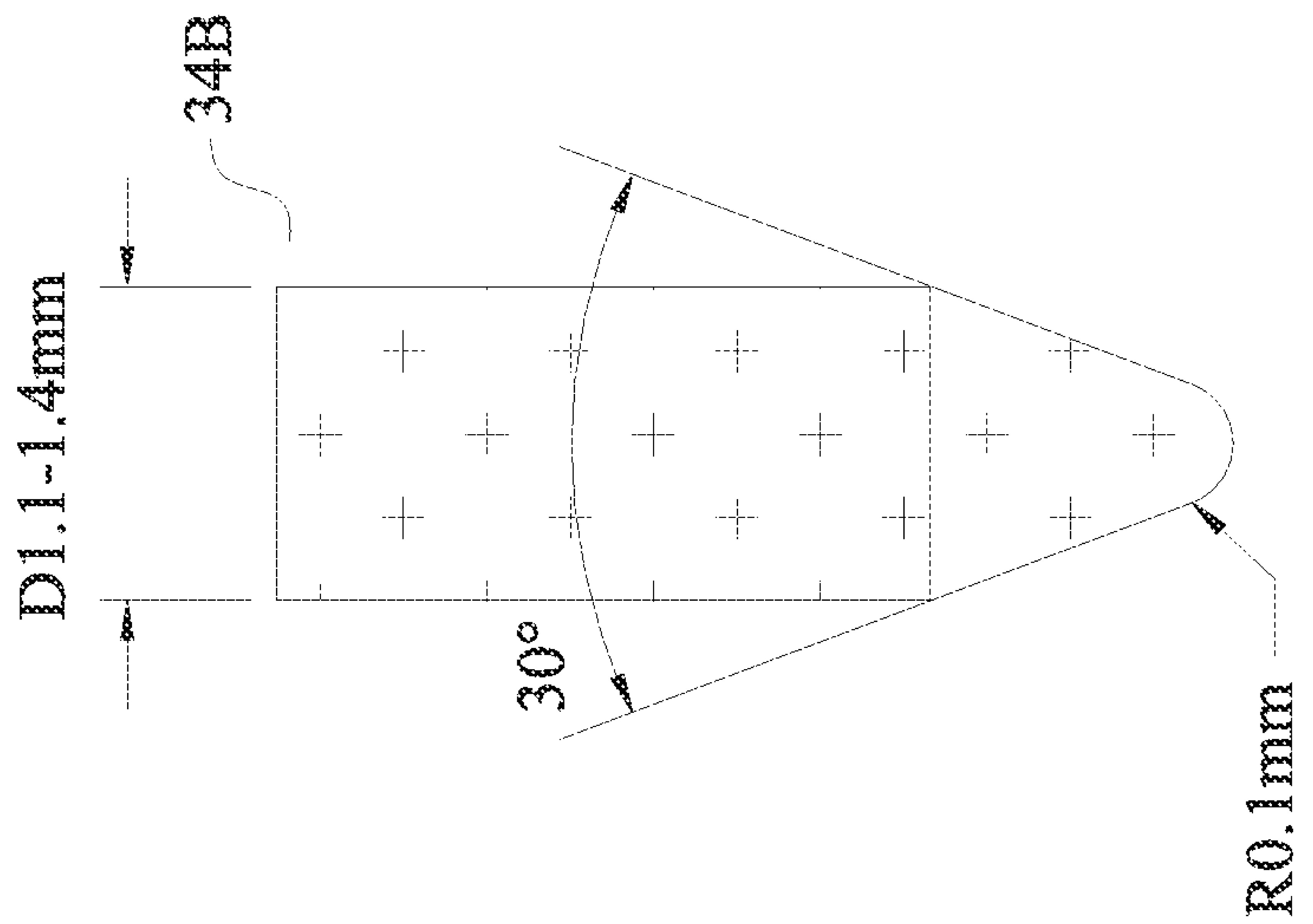


FIG. 7B

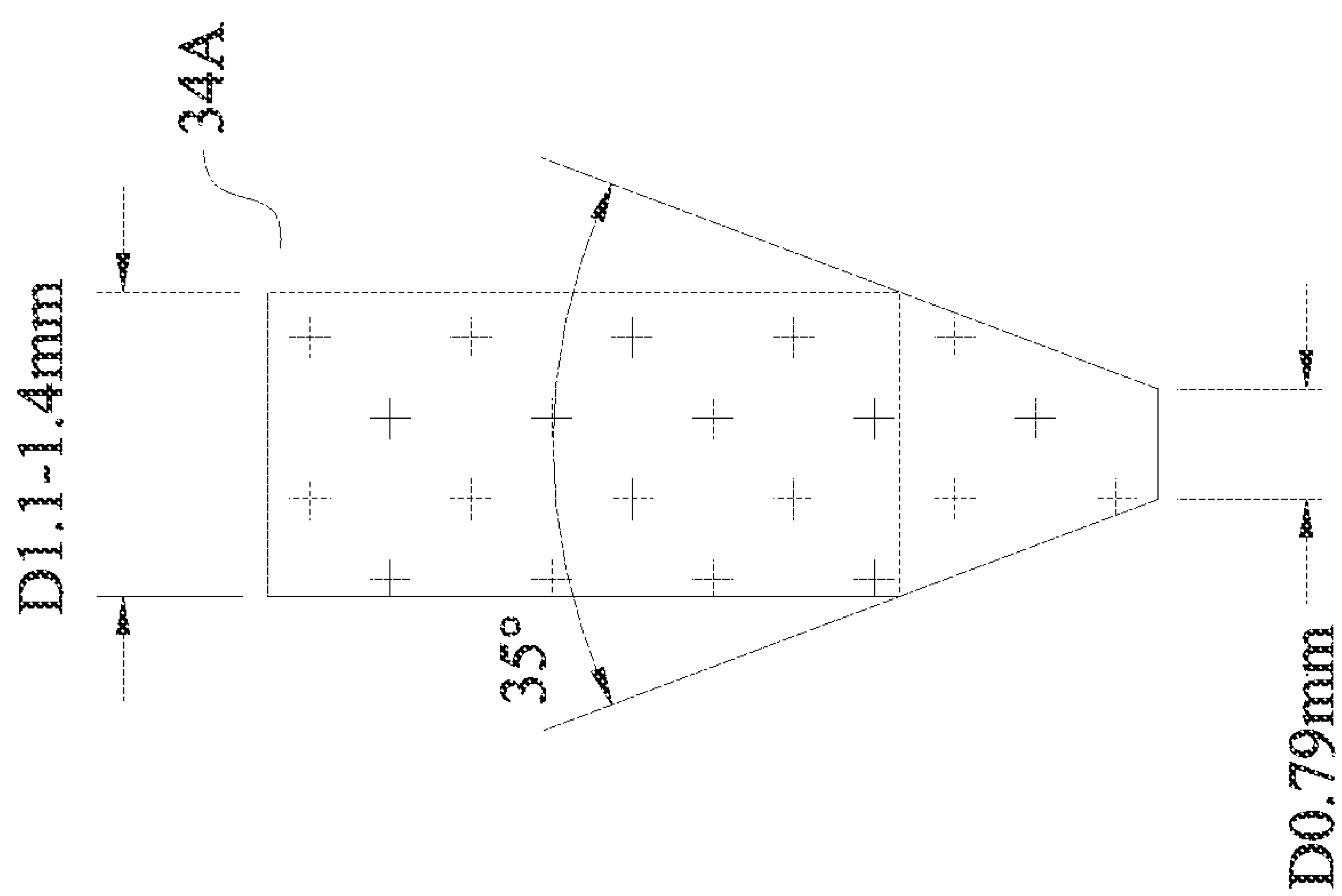


FIG. 7A

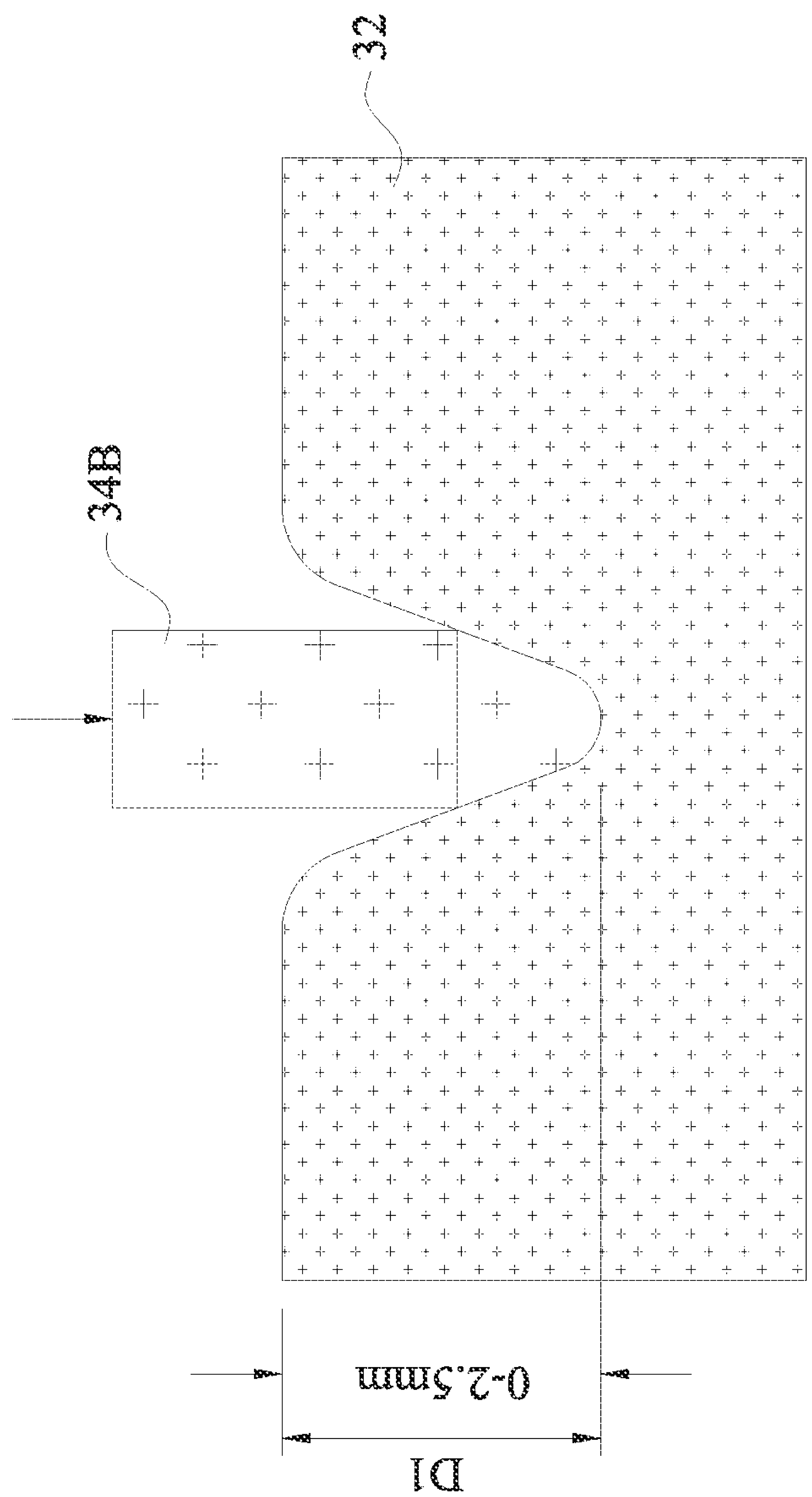


FIG. 8

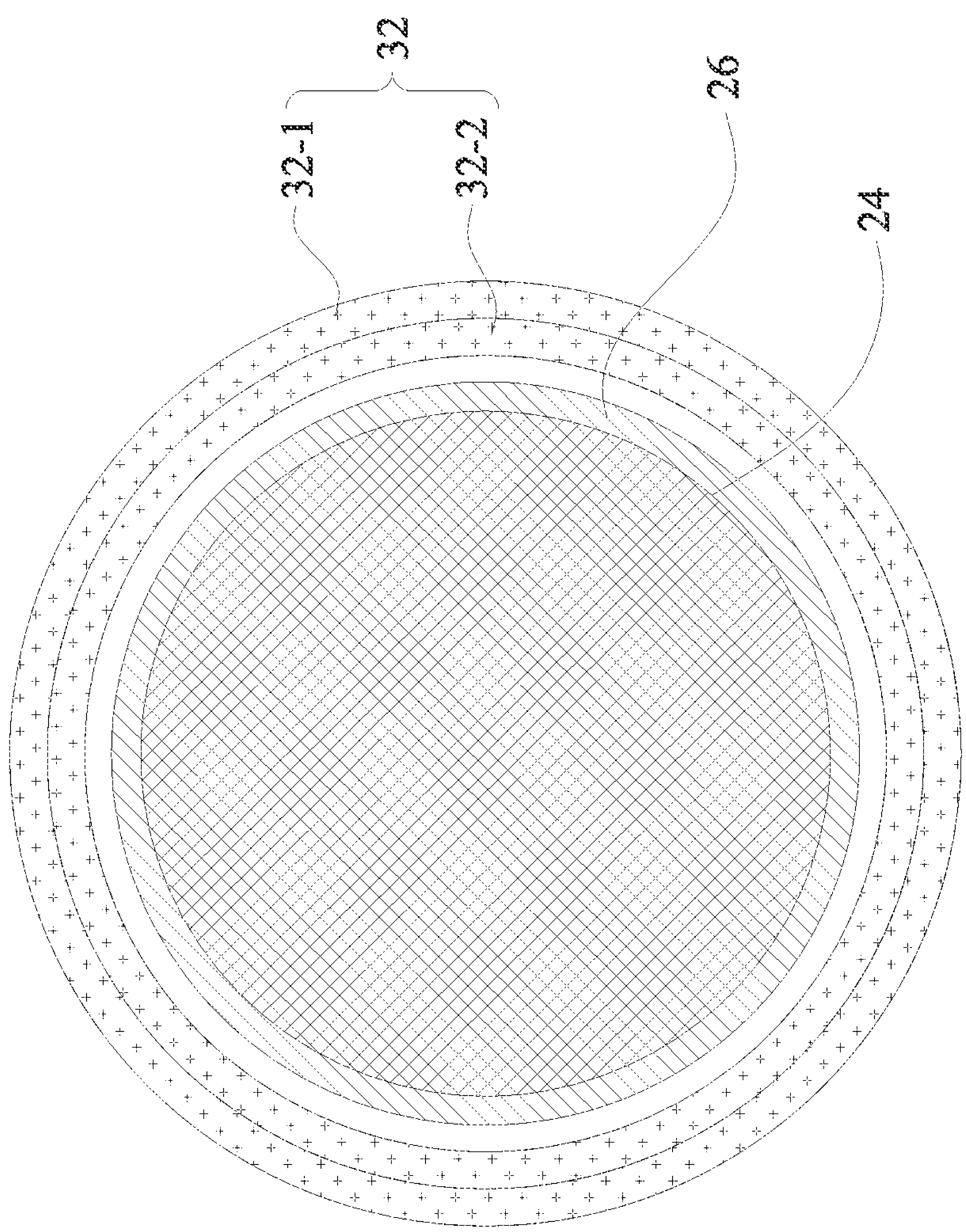


FIG. 9

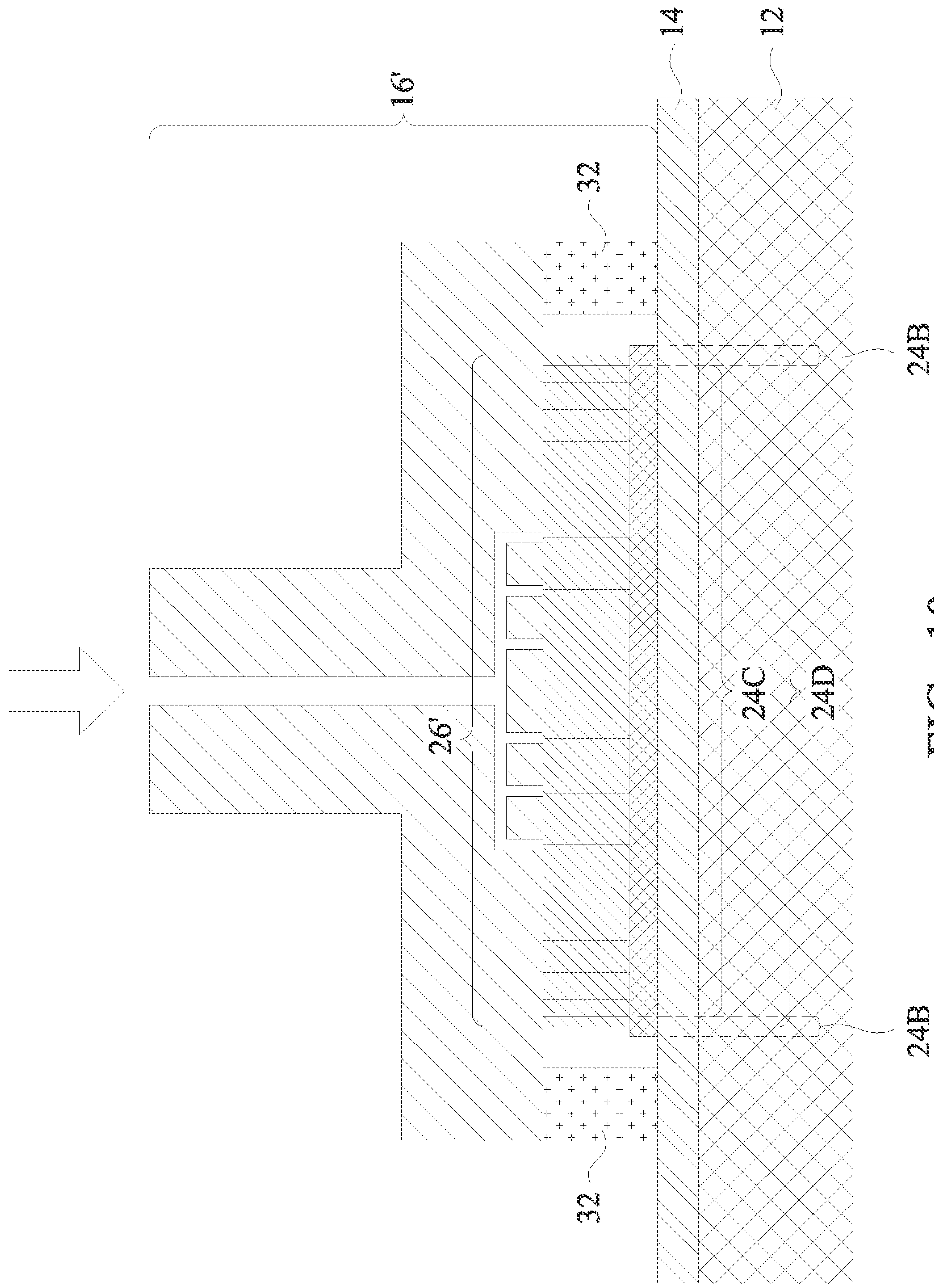


FIG. 10

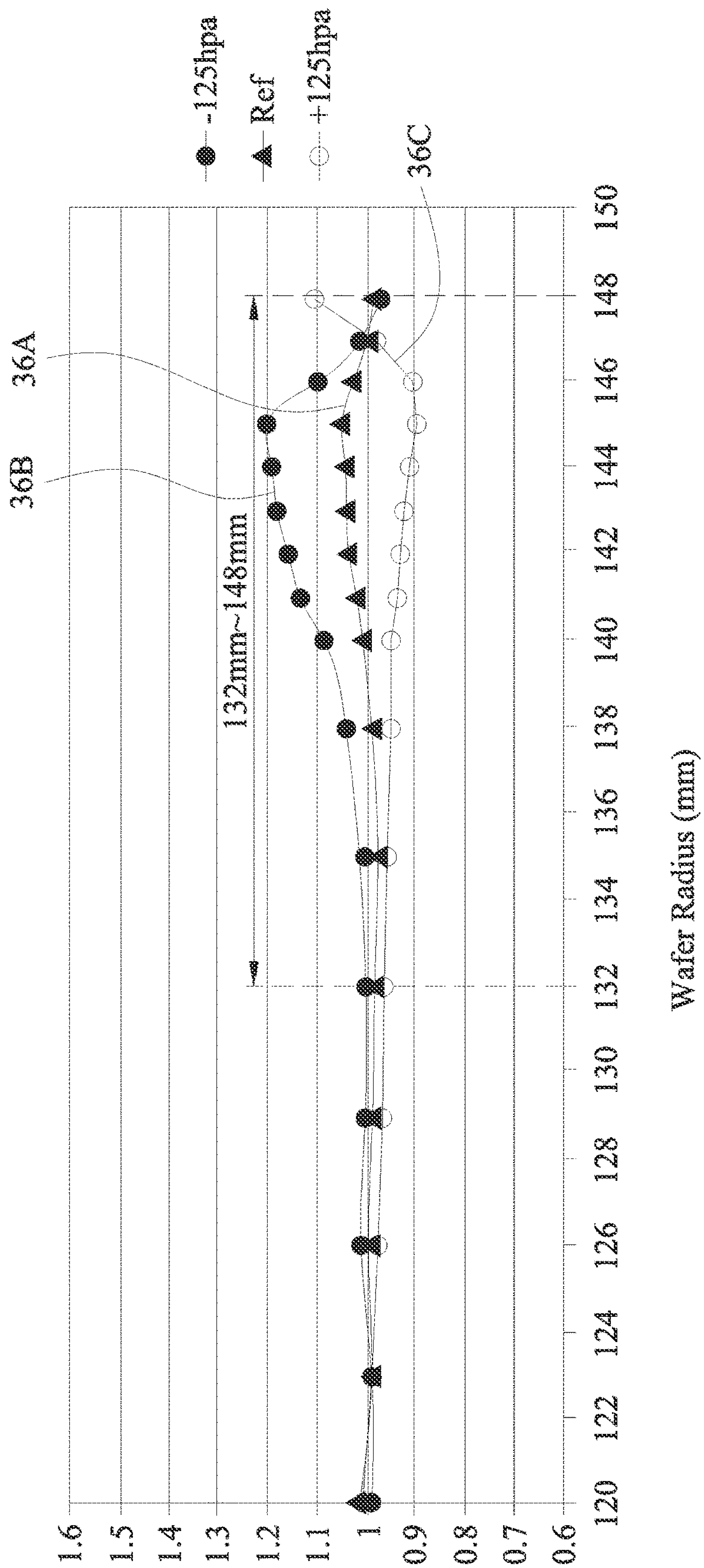
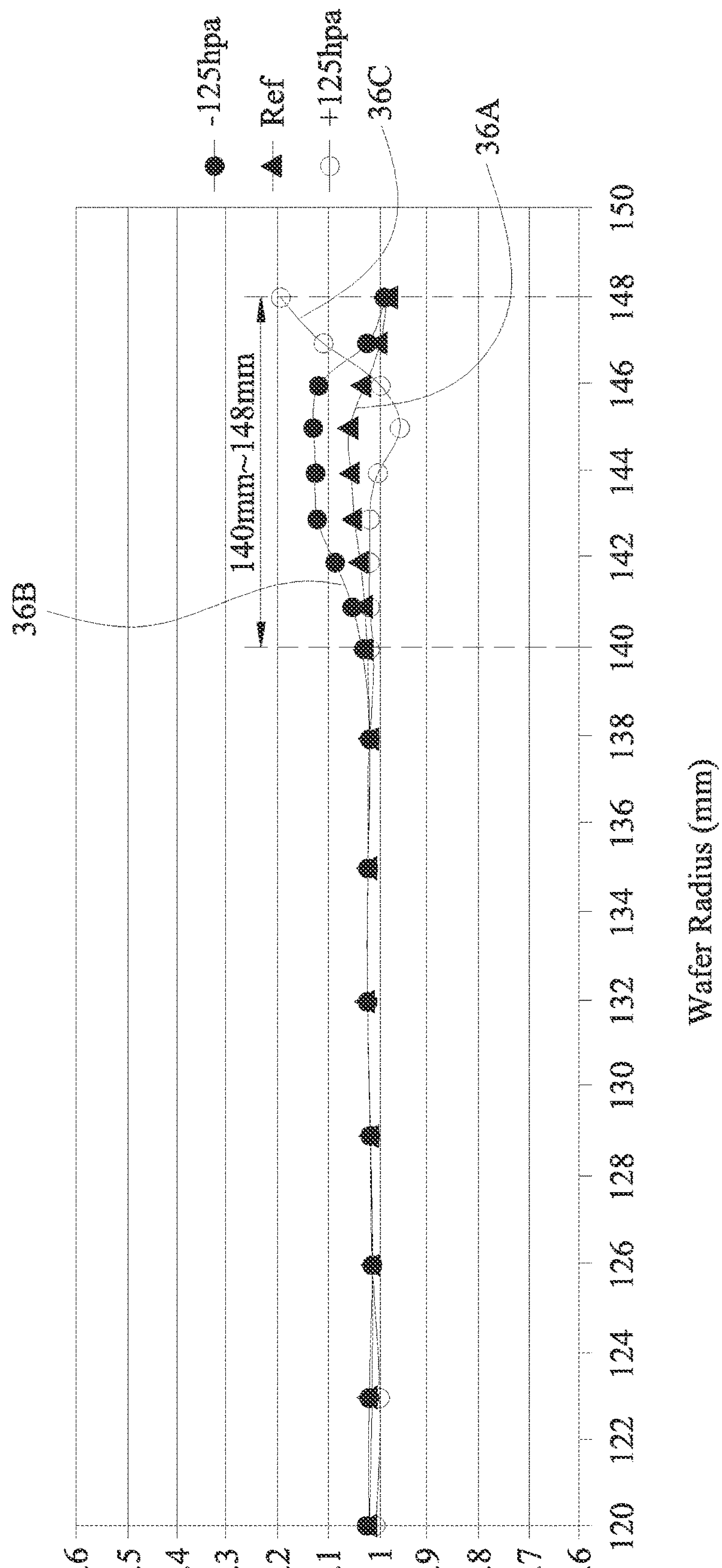

-125hpa
Ref
+125hpa
36A
36B
36C
132mm~148mm
Normalizod RR (a.u.)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
Wafer Radius (mm)
120
122
124
126
128
130
132
134
136
138
140
142
144
146
148
150

FIG. 11A



-125hpa
Ref
+125hpa
36C
36A
36B
140mm~148mm
Normalizod RR (a.u.)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
Wafer Radius (mm)
120
122
124
126
128
130
132
134
136
138
140
142
144
146
148
150

FIG. 11B

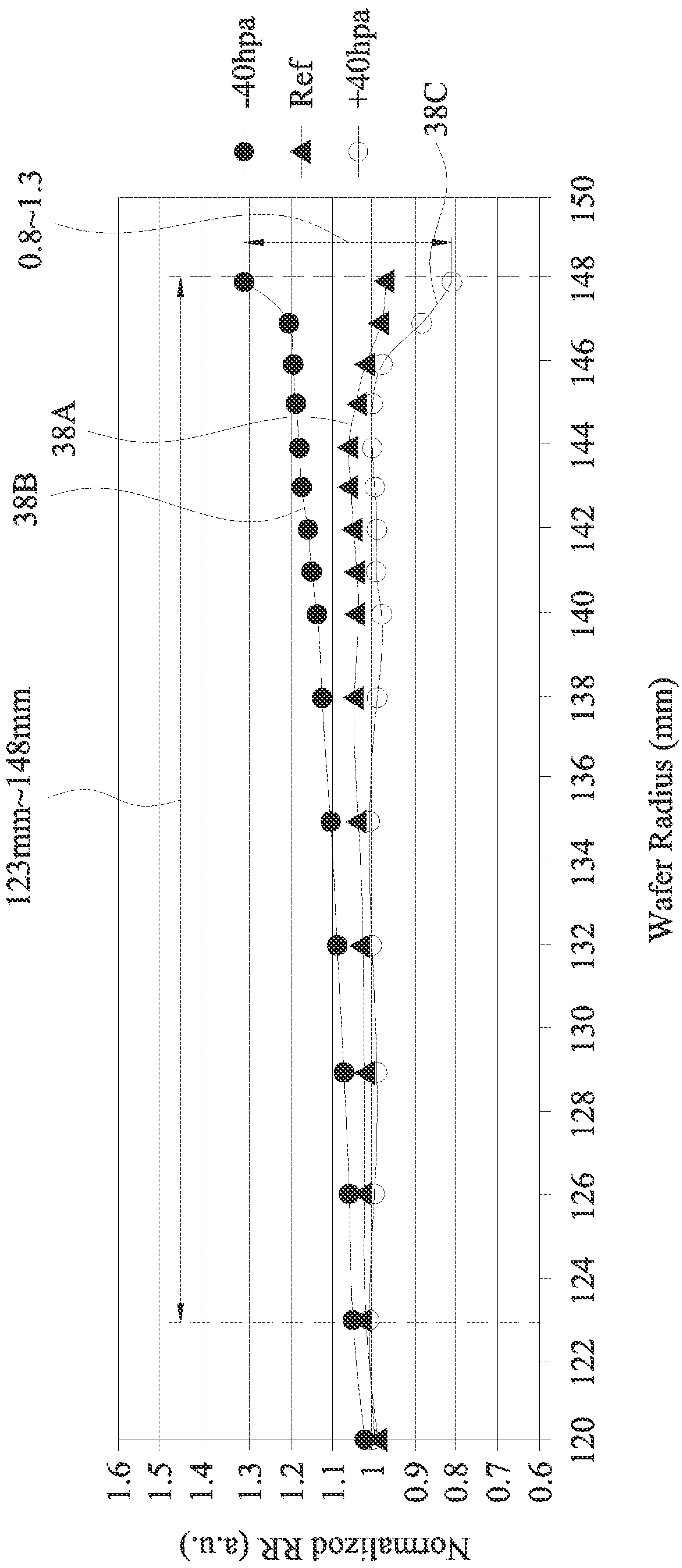
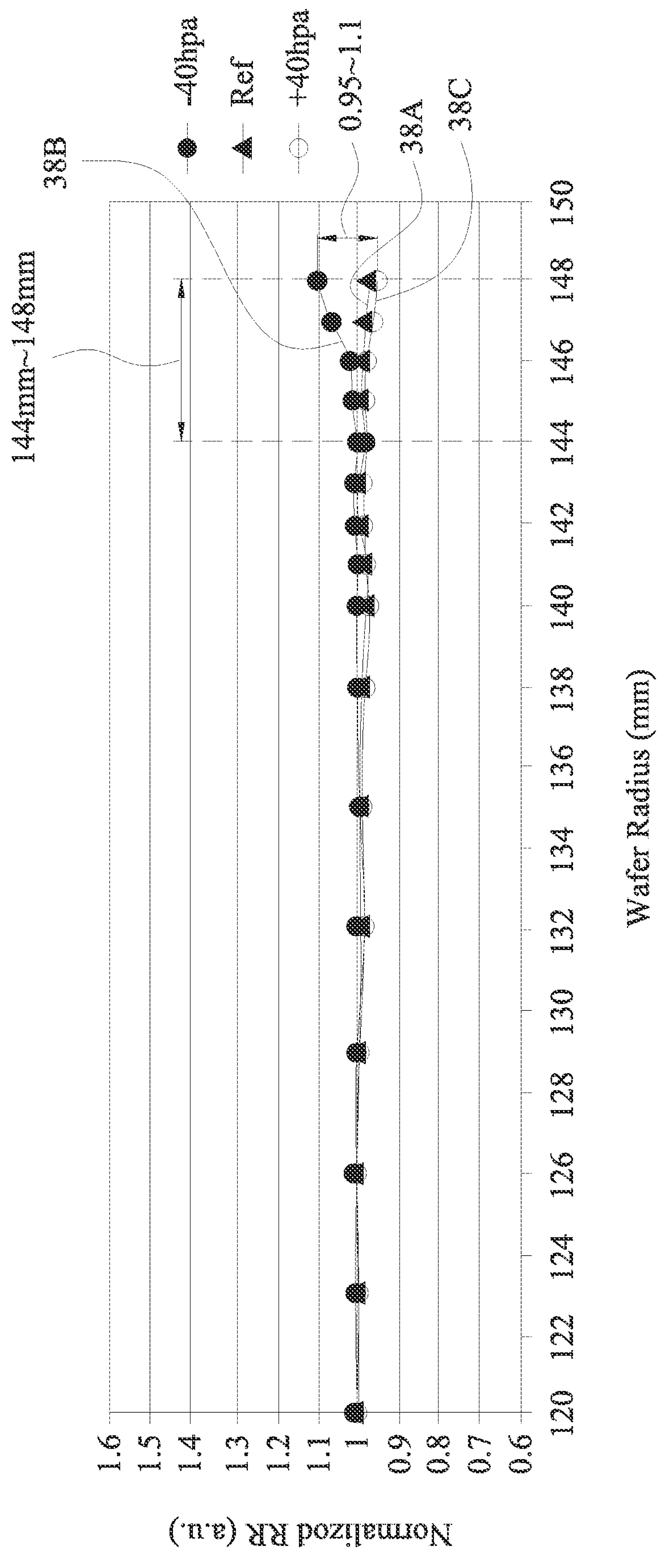

-40hpa
Ref
+40hpa
38C
0.8~1.3
38A
38B
123mm~148mm
Normalizod RR (a.u.)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
120
122
124
126
128
130
132
134
136
138
140
142
144
146
148
150
Wafer Radius (mm)

FIG. 12A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Ref
+40hpa
0.95~1.1
38A
38C
38B
144mm~148mm
Normalizod RR (a.u.)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
120
122
124
126
128
130
132
134
136
138
140
142
144
146
148
150
Wafer Radius (mm)

FIG. 12B

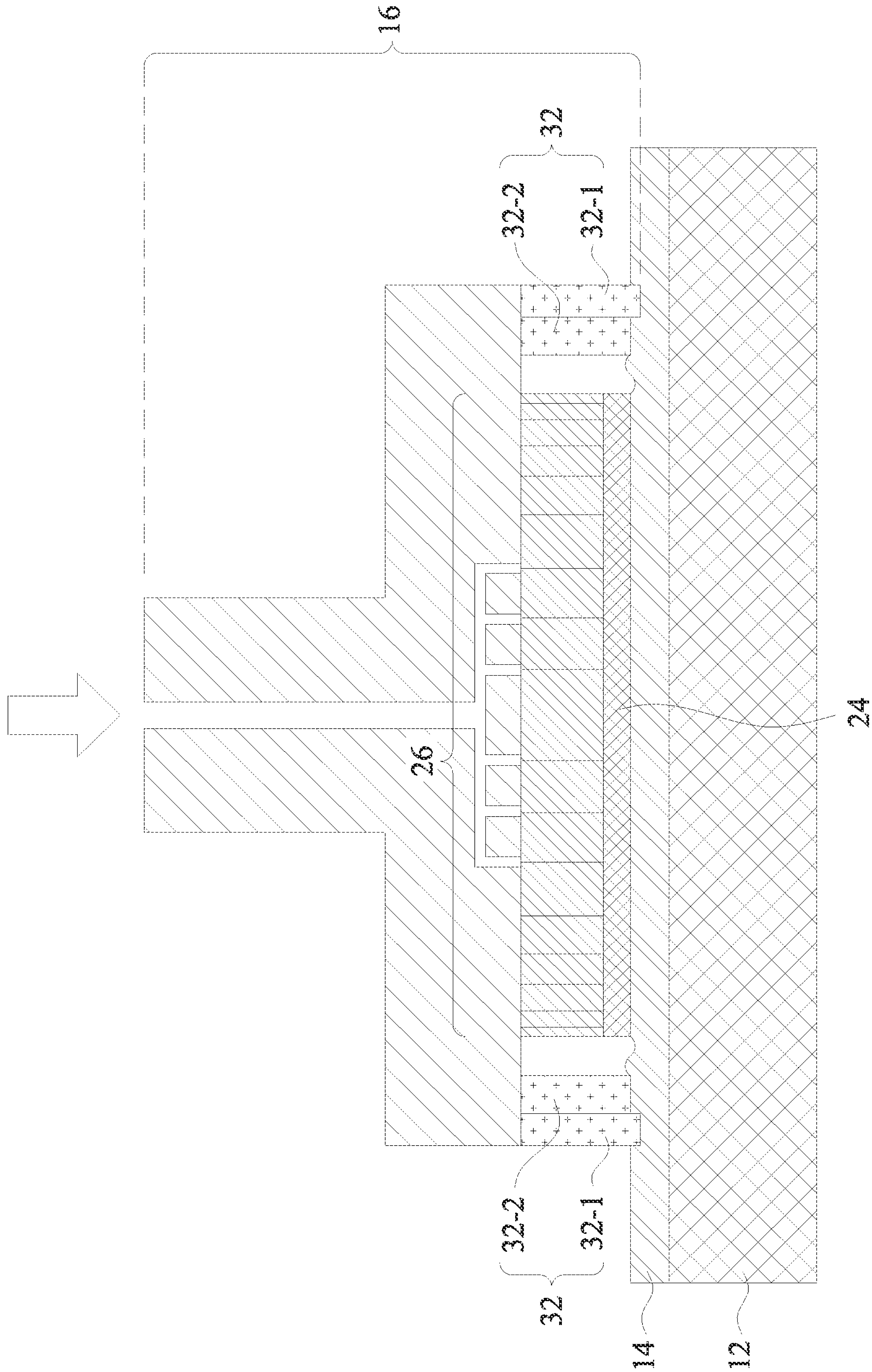

FIG. 13

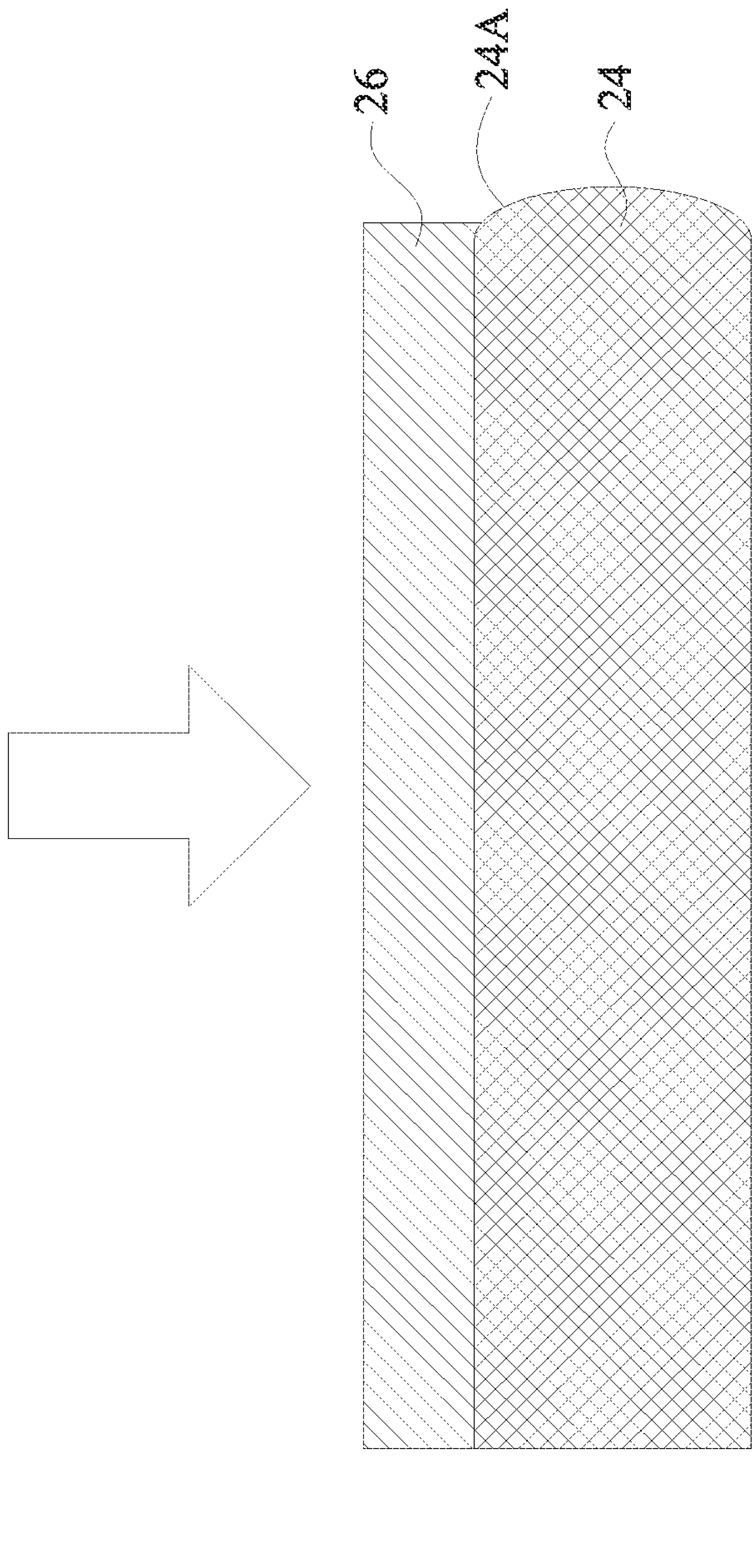

FIG. 14

CMP POLISHING HEAD DESIGN FOR IMPROVING REMOVAL RATE UNIFORMITY

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 16/225,792, filed on Dec. 19, 2018, entitled "CMP Polishing Head Design for Improving Removal Rate Uniformity," which is a continuation of U.S. patent application Ser. No. 14/942,582, filed on Nov. 16, 2015, now U.S. Pat. No. 10,160,091 issued Dec. 25, 2018, entitled "CMP Polishing Head Design for Improving Removal Rate Uniformity," each patent application is incorporated herein by reference.

BACKGROUND

Chemical Mechanical Polishing (CMP) is a common practice in the formation of integrated circuits. Typically, CMP is used for the planarization of semiconductor wafers. CMP takes advantage of the synergetic effect of both physical and chemical forces for the polishing of wafers. It is performed by applying a load force to the back of a wafer while the wafer rests on a polishing pad. A polishing pad is placed against the wafer. Both the polishing pad and the wafer are then counter-rotated while a slurry containing both abrasives and reactive chemicals is passed therebetween. CMP is an effective way to achieve global planarization of wafers.

A truly uniform polishing, however, is difficult to achieve due to various factors. For example, slurries are dispensed either from the top or bottom of the polishing pad. This will result in non-uniformity in polish rate for different locations of the wafer. If slurries are dispensed from the top, the edges of the wafers typically have higher CMP rates than the centers. Conversely, if slurries are dispensed from the bottom, the centers of the wafers typically have higher CMP rates than the edges. Furthermore, the non-uniformity may also be introduced from the non-uniformity in the pressure applied to different locations of the wafer. To reduce the non-uniformity in polishing rate, pressures applied on different locations of the wafers are adjusted. If the CMP rate in one region of a wafer is low, a higher pressure is applied to this location to compensate the low removal rate.

BRIEF DESCRIPTION OF THE DRAWINGS

Aspects of the present disclosure are best understood from the following detailed description when read with the accompanying figures. It is noted that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

FIG. **1** illustrates an apparatus for performing Chemical Mechanical Polishing (CMP) in accordance with some embodiments.

FIGS. **2** through **5** illustrate the cross-sectional views of intermediate stages of a CMP process in accordance with some embodiments.

FIG. **6** illustrates a top view of a retaining ring and a membrane in accordance with some embodiments.

FIGS. **7**A and **7**B and **8** illustrate indenters and a method, respectively, for determining hardness of a material in accordance with some embodiments.

FIG. **9** illustrates a top view of a retaining ring and a membrane in accordance with some embodiments.

FIG. **10** illustrates the cross-sectional view of a conventional CMP process.

FIGS. **11**A and **11**B illustrate the normalized removal rate non-uniformity as a function of the locations on a wafer, wherein the effect of increasing the inner diameter of a retaining ring is illustrated.

FIGS. **12**A and **12**B illustrate the normalized removal rate non-uniformity as a function of the locations on a wafer, wherein the effect of increasing the inner diameter of a retaining ring and extending a membrane to wafer edge is illustrated.

FIG. **13** illustrates the CMP of a wafer in accordance with some embodiments, wherein the inner diameter of a retaining ring and an outer diameter of a membrane are both increased.

FIG. **14** illustrates a magnified view of a portion of a wafer and a membrane in accordance with some embodiments.

DETAILED DESCRIPTION

The following disclosure provides many different embodiments, or examples, for implementing different features of the invention. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. For example, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed between the first and second features, such that the first and second features may not be in direct contact. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

Further, spatially relative terms, such as "underlying," "below," "lower," "overlying," "upper" and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly.

A Chemical Mechanical Polishing (CMP) apparatus is provided in accordance with various exemplary embodiments. The variations of some embodiments are discussed. Throughout the various views and illustrative embodiments, like reference numbers are used to designate like elements. The embodiments of the present disclosure also include the scope of using the CMP apparatus in accordance with the embodiments to manufacture integrated circuits. For Example, the CMP apparatus is used to planarize wafers, in which integrated circuits are formed.

FIG. **1** schematically illustrates a perspective view of a part of a CMP apparatus/system in accordance with some embodiments of the present disclosure. CMP system **10** includes polishing platen **12**, polishing pad **14** over polishing platen **12**, and polishing head **16** over polishing pad **14**. Slurry dispenser **18** has an outlet directly over polishing pad

14 in order to dispense slurry onto polishing pad **14**. Disk **20** is also placed on the top surface of polishing pad **14**.

During the CMP, slurry **22** is dispensed by slurry dispenser **18** onto polishing pad **14**. Slurry **22** includes a reactive chemical(s) that react with the surface layer of the wafer **24** (FIG. **5**). Furthermore, slurry **22** includes abrasive particles for mechanically polishing the wafer.

Polishing pad **14** is formed of a material that is hard enough to allow the abrasive particles in the slurry to mechanically polish the wafer, which is under polishing head **16**. On the other hand, polishing pad **14** is also soft enough so that it does not substantially scratch the wafer. During the CMP process, polishing platen **12** is rotated by a mechanism (not shown), and hence polishing pad **14** fixed thereon is also rotated along with polishing platen **12**. The mechanism (such as a motor) for rotating polishing pad **14** is not illustrated.

On the other hand, during the CMP process, polishing head **16** is also rotated, and hence causing the rotation of wafer **24** (FIG. **2**) fixed onto polishing head **16**. In accordance with some embodiments of the present disclosure, as shown in FIG. **1**, polishing head **16** and polishing pad **14** rotate in the same direction (clockwise or counter-clockwise). In accordance with alternative embodiments, polishing head **16** and polishing pad **14** rotate in opposite directions. The mechanism for rotating polishing head **16** is not illustrated. With the rotation of polishing pad **14** and polishing head **16**, slurry **22** flows between wafer **24** and polishing pad **14**. Through the chemical reaction between the reactive chemical in the slurry and the surface layer of wafer **24**, and further through the mechanical polishing, the surface layer of wafer **24** is removed.

FIG. **1** also illustrates disk **20** over polishing pad **14**. Disk **20** is configured to remove undesirable by-products generated during the CMP process. In accordance with some embodiments of the present disclosure, disk **20** contacts the top surface of polishing pad **14** when polishing pad **14** is to be conditioned. During the conditioning, both polishing pad **14** and disk **20** rotate, so that the protrusions or cutting edges of disk **20** move relatively to the surface of polishing pad **14**, and hence polishing and re-texturizing the surface of the polishing pad **14**.

FIGS. **2** through **5** illustrate cross-sectional views of intermediate stages in an exemplary CMP process. Referring to FIG. **2**, polishing head **16** is provided. Polishing head **16** includes wafer carrier assembly **17**, which is configured to hold and fix wafer **24** in various process steps. Wafer carrier assembly **17** includes air passages **30**, in which vacuum may be generated. By vacuuming air passages **30**, wafer **24** is sucked up for the transportation of wafer **24** to and away from polishing pad **14** (FIG. **1**).

As shown in FIG. **2**, polishing head **16** is moved over wafer **24**, which is placed over wafer stage **28**. Next, referring to FIG. **3**, vacuum is generated in air passages **30**, and wafer **24** is picked up. Although not shown in FIG. **3**, air passages **30** also include some portions in flexible membrane **26**, and hence when wafer **24** is picked up, the bottom surface of flexible membrane **26** contacts the top surface of wafer **24**. The picked-up wafer **24** is located in the space defined by retaining ring **32**, which forms a circular ring. When picking up wafer **24**, the central axis of polishing head **16** is aligned to the center of wafer **24**, so that the edges of wafer **24** may be equally spaced from the respective inner edges **32**A of retaining ring **32** by gaps G1, which may be a substantially uniform gap around wafer **24**.

Referring to FIG. **4**, polishing head **16** is moved over polishing pad **14**, which is further located on platen **12**. In accordance with some embodiments of the present disclosure, the illustrated portion of polishing pad **14** is not the center portion of polishing pad **14**. Rather, as illustrated in FIG. **1**, the illustrated portion is offset from the central axis of polishing pad **14**. For example, the central axis of polishing pad **14**, along with polishing pad **14** rotates, may be on the left side or right side of the illustrated portion.

Next, referring to FIG. **5**, polishing head **16** is placed on, and also pressed against, polishing pad **14**. The vacuuming in air passages **30** is then turned off, and hence wafer **24** is no longer sucked up. Flexible membrane **26** is inflated, for example, by pumping air into the plurality of zones **26**A in flexible membrane **26**. In accordance with some embodiments of the present disclosure, flexible membrane **26** is formed of a flexible and elastic material, which is formed of ethylene propylene rubber, neoprene rubber, nitrile rubber, or the like. The inflated flexible membrane **26** thus presses wafer **24** against polishing pad **14**.

Membrane **26** includes a plurality of zones **26**A. Each of zones **26**A includes a chamber sealed by the flexible and elastic material. In a top view of flexible membrane **26**, zones **26**A have circular shapes, which may be concentric. Each of zones **26**A is separated from other zones, and hence each of zones **26**A may be inflated to have a pressure different from or equal to the pressures in other zones. Accordingly, the pressure applied by individual zones may be adjusted to improve the removal rate uniformity of the CMP. For example, by increasing the pressure of a zone, the polishing rate of the wafer portion directly under the zone may be increased, and vice versa.

When polishing head **16** is pressed against polishing pad **14**, the bottom surface of retaining ring **32** is in physical contact with, and is pressed against, polishing pad **14**. While not shown, the bottom surface of retaining ring **32** has some grooves, which allow slurry to get in and out of retaining ring **32** during the rotation of polishing head **16** (and retaining ring **32**).

With wafer **24** being pressed against polishing pad **14**, polishing pad **14** and polishing head **16** rotate, resulting in the rotation of wafer **24** on polishing pad **14**, and hence the CMP is conducted. During the CMP, retaining ring **32** functions to retain wafer **24** in case wafer **24** is offset from the central axis of polishing head **16**, so that wafer **24** is not spun off from polishing pad **14**. In normal operation, however, retaining ring **32** may not be in contact with wafer **24**.

FIG. **5** illustrates an exemplary retaining ring **32** in accordance with some embodiments of the present disclosure. Retaining ring **32** includes outer ring **32-1** and inner ring **32-2**. Each of outer ring **32-1** and inner ring **32-2** forms a full ring, which may have a uniform thickness measured in the radius direction of retaining ring **32**, and measured at the bottoms of rings **32-1** and **32-2**. For example, FIG. **6** illustrates a bottom view of retaining ring **32**, wherein outer ring **32-1** encircles inner ring **32-2**. The outer ring **32-1** and inner ring **32-2** are joined together to form the integrated retaining ring **32**. Each of thickness T1 of outer ring **32-1** and thickness T2 of inner ring **32-2** may be in the range between about ⅓ and about ⅔ of the total thickness (T1+T2), so that outer ring **32-1** has enough thickness for it to press on polishing pad **14**, and inner ring **32-2** has enough thickness to press polishing pad **14** while at the same time yield to the force from polishing pad **14** as needed.

Referring back to FIG. **4**, before retaining ring **32** is pressed on polishing pad **14**, the bottom surface of inner ring **32-2** is coplanar with the bottom surface of outer ring **32-1**. In accordance with some exemplary embodiments, both inner ring **32-2** and outer ring **32-1** are formed of wearresistant materials, which may be plastic, ceramic, polymer, etc. For example, each of inner ring **32-2** and outer ring **32-1** may be formed of polyurethane, polyester, polyether, polycarbonate, or combination thereof. In accordance some with exemplary embodiments, inner ring **32-2** and/or outer ring **32-1** is formed of polyphenylene sulfide (PPS), polyetheretherketone (PEEK), or the mix of these materials and other materials such as polymers (for example, polyurethane, polyester, polyether, or polycarbonate). The compositions of inner ring **32-2** and outer ring **32-1** are different from each other. In accordance with some embodiments, the materials of inner ring **32-2** and outer ring **32-1** are the same as each other, but with different percentages (and hence their materials are still different from each other). In accordance with other embodiments, inner ring **32-2** and outer ring **32-1** are formed of different materials, with at least one material presented in either inner ring **32-2** or outer ring **32-1** not presented in the other.

In accordance with some embodiments of the present disclosure, inner ring **32-2** is formed of a material that is softer than the material of outer ring **32-1**. Alternatively stated, the hardness of inner ring **32-2** is lower than the hardness of outer ring **32-1**. Accordingly, as shown in FIG. **5**, the bottom surface of inner ring **32-2** is higher than the bottom surface of outer ring **32-1** by height difference ΔH. In accordance with some embodiments, height difference ΔH is greater than about 0.01 mm, and may be in the range between about 0.01 mm and about 3 mm. It is appreciated that height difference ΔH depends on the retaining ring down force during the CMP process, and greater force results in greater height difference ΔH. The hardness of materials may be measured and represented using various ways including, and not limited to, Shore (durometer) hardness test and Rockwell Hardness test. The hardness of materials may also be represented using Young's modulus.

For example, FIGS. **7**A and **7**B illustrate the indenters for testing the hardness of a material in the Shore test, wherein the indenters are commonly used for testing the hardness of polymers, rubbers, plastics, and/or the like. In Shore hardness test, the hardness of a material is measured by measuring the resistance of the material to the pressing of a spring-loaded needle-like indenter. FIG. **7**A illustrates commonly used indenter **34**A, and FIG. **7**B illustrates commonly used indenter **34**B. The shape and the dimensions are schematically illustrated in FIGS. **7**A and **7**B. Using the indenter **34**A as shown in FIG. **7**A or indenter **34**B as shown in **7**B, the hardness of a material can be measured. The hardness measured using indenter **34**A in FIG. **7**A is referred to as Shore A hardness (scale), and the hardness measured using indenter **34**B in FIG. **7**B is referred to as Shore D hardness (scale).

Shore A scale is used for testing soft elastomers (rubbers) and other soft polymers. The hardness of hard elastomers and most other polymer materials are measured by Shore D scale. Shore hardness is tested with an instrument called durometer, which utilizes an indenter (such as **34**A or **34**B) loaded by a calibrated spring (not shown). The hardness is determined by the penetration depth of the indenter under the load. The loading force of Shore D test is 10 pounds (4,536 grams), and the loading force of Shore A test is 1.812 pounds (822 grams). Shore hardness values may vary in the range from 0 to 100. The maximum penetration for each of Shore A and Shore D is 0.097 to 0.1 inch (2.5 mm to 2.54 mm), which correspond to the minimum shore hardness of 0. The maximum hardness value 100 corresponds to zero penetration.

FIG. **8** illustrates the measurement of Shore D hardness of material **32**, wherein penetration depth D**1** reflects the Shore D hardness value. It is realized when indenter **34**B is replaced with the indenter **34**A as shown in FIG. **7**A, Shore A hardness may be obtained. Shore A hardness and shore D hardness may be converted to each other using Table 1.

TABLE 1

	Short A														
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Shore D	6	7	8	10	12	14	16	19	22	25	29	33	39	46	58

Referring back to FIG. **5**, in accordance with some exemplary embodiments of the present disclosure, outer ring **32-1** has Shore D hardness in the range between about 80 and about 90, and inner ring **32-2** has Shore D hardness in the range between about 15 and about 65. In accordance with some embodiments, the Shore D hardness value of outer ring **32-1** may be greater than the Shore D hardness value of inner ring **32-2** by about 30 or more.

Referring to FIG. **4**, before retaining ring **32** is pressed against polishing pad **14**, the bottom surfaces of outer ring **32-1** and inner ring **32-2** are coplanar with each other. After retaining ring **32** is pressed against polishing pad **14**, as shown in FIG. **5**, inner ring **32-2**, due to its lower hardness, yields more to the pressure from polishing pad **14** than outer ring **32-1**, resulting in a smaller force applied to the portions of polishing pad **14** directly under inner ring **32-2**. Alternatively stated, the deformation of polishing pad **14** becomes smaller. This advantageously improves the uniformity in the removal rate of wafer **24** during the CMP, wherein the removal rate is calculated as the removed thickness per unit time.

The mechanism of the improvement in the removal rate uniformity is explained referring to FIG. **5**. Retaining ring **32** pushes polishing pad **14**, causing the adjacent part of polishing pad **14** to deform. The part **14**A of polishing pad **14** immediately next to the inner edge of retaining ring **32** may protrude, and the part of polishing pad **14** next to the protruding part **14**A may recess. This causes the force applied by the portions of polishing pad **14** underlying wafer **24** to vary, and hence the removal rate uniformity of wafer **24** is adversely affected. For example, as shown in FIG. **5**, void **35** is illustrated to represent that these edge portions of wafer **24** may receive reduced forces (and sometimes actual voids occur) from polishing pad **14** than the inner portions of wafer **24**, and the removal rate of the edge portions of wafer **24** is at least reduced compared to the inner portions, wherein the removal rate of the edge portions may be reduced to zero in some cases due to voids under wafer **24**. In the embodiments of the present disclosure, with the inner ring **32-2** being softer, the deformation of polishing pad **14** is less severe, and hence the non-uniformity in the removal rate is reduced.

In accordance with some embodiments of the present application, the multi-layer retaining ring **32** may include three, four, or more (sub) rings formed of different materials, with the outer (sub) rings encircling the inner (sub) rings. From the outer rings to the inner rings, the hardness values are increasingly smaller to maximize the benefit of reducing the non-uniformity in the removal rate. For example, FIG. **6** illustrates that there may be more rings **32-3** and **32-4**, which are illustrated using dashed lines to represent these rings may or may not exist. Similar to the embodiments as shown in FIG. **4**, the bottom surfaces of rings **32-1**, **32-2**, **32-3**, and **32-4** may be coplanar with each other when retaining ring **32** is not pressed against polishing pad **14**. When retaining ring **32** is pressed against polishing pad **14**, the bottom surfaces of rings **32-1**, **32-2**, **32-3**, and **32-4** are non-coplanar, with the inner rings having bottom surfaces increasingly higher than the bottom surfaces of the respective outer rings. Furthermore, depending on the total number of sub rings, the difference in shore D values of neighboring sub rings may be greater than 5, greater than 10, or greater than 15 or 30 in various embodiments. In yet alternative embodiments, retaining ring **32** has a gradually and continuously reduced hardness from outer edge to the inner edge, with the hardness difference between the outmost material and the inner most material being greater than about 30 on Shore D scale, for example. The material of retaining ring **32** also has gradually and continuously changed compositions in order to have the changed hardness.

Referring again to FIG. **5**, membrane **26** extends to edge **24**A of wafer **24**, and applies pressing force to the very edge portion of wafer **24**. Accordingly, an entire top surface of wafer **24** receives the pressing force from membrane **26**. In addition, the force applied to the center of wafer **24** may be equal to, or substantially equal, the force applied to the very edge portion of wafer **24**. For example, the force applied to the edge of wafer **24** may be in the range between about 90 percent and about 110 percent (or between about 95 percent and about 105 percent) the force applied to the center of wafer **24**. Some wafers may be curved at edges, wherein the curved edges connect the planar top surface to the planar bottom surface. In these embodiments, flexible membrane at least contacts up to the interface between the planar top surface and the curved edges, and may also contact and apply force to some of the curved edges, as illustrated in FIG. **14**.

Referring again to FIG. **6**, which illustrates the bottom view of wafer **24** and membrane **26**, membrane **26** extends to the edge of wafer **24**, and hence membrane **26** is shown as overlapping wafer **24**. FIG. **9** illustrates the bottom view of wafer **24** and membrane **26** in accordance with other embodiments, wherein membrane **26** extends beyond the edges of wafer **24** slightly, so that a margin is left to ensure the entire top surface of wafer **24** (FIG. **5**) receives the pressing force from membrane **26**.

FIG. **10** illustrates polishing head **16** and wafer **24** in a conventional setting. As shown in FIG. **10**, wafer **24** includes wafer-edge region **24**B and inner region **24**C. The wafer-edge region **24**B forms a ring encircling inner region **24**C. The complete dies are sawed from the inner region **24**C, but not from wafer-edge region **24**B. Accordingly, in the conventional setting, membrane **26'** was in contact with the top surface of inner region **24**C but not the entirety of the top surface of the wafer-edge region **24**B. Accordingly, in the conventional setting, portion **24**D of wafer **24** is pressed by membrane **26'**.

In accordance with some embodiments, the inner diameter of retaining ring **32** may also be increased to improve the removal rate uniformity. The increase in the inner diameter of retaining ring **32** is achieved by increasing gap G**1** (FIG. **5**). In accordance with some embodiments of the present invention, for a 300 mm wafer, gap G**1** as shown in FIG. **5** may be increased from 0.5 mm to greater than about 1 mm, or greater than about 1.5 mm. This causes significant improvement in the uniformity. As a result, as shown in FIG. **13**, the deformation region of polishing pad (caused by the pressing of retaining ring **32**) is shifted away from wafer **24** (as compared to FIG. **5**), resulting in an improved removal rate uniformity. FIGS. **11**A and **11**B illustrate the results obtained from silicon wafer samples, and the results demonstrate the effect of increasing gap G**1** (and hence the increasing in inner diameter of retaining ring **32**). FIG. **11**A illustrates the results corresponding to gap G**1** of 0.5 mm, and FIG. **11**B illustrates the results corresponding to gap G**1** of 1.5 mm.

In each of FIGS. **11**A and **11**B, the X-axis illustrates the wafer radius, which represents the distance of points on a sample wafer to the center of the wafer having a diameter of 300 mm. Accordingly, distance of 150 mm represents the wafer edge, and distance of 138 mm represents the edge of inner region **24**C (FIG. **10**), from which the complete dies are obtained. The Y-axis represents the normalized removal rate. Line **36**A is obtained by applying a reference pressure to polishing pad **14** through retaining ring **32** so that the removal rates in the inner region (**24**C in FIG. **10**) of the sample wafer are substantially uniform. Line **36**B is obtained by increasing the pressure of retaining ring by 125 hectopascals (hpa) relative to the reference pressure. As shown in by line **36**B, by increasing the pressure of the retaining ring, the removal rate of the edge portions of the sample wafer is increased. Line **36**C is obtained by reducing the pressure of retaining ring by 125 hpa relative to the reference pressure. As shown in by line **36**C, by reducing the pressure of the retaining ring, the removal rate of the edge portions of the sample wafer is reduced. Furthermore, lines **36**B and **36**C illustrate that the non-uniformity of the removal rates is affected by the pressure applied by the retaining ring. In FIG. **11**A, the non-uniform region spans from about 132 mm (from wafer center) to about 148 mm. The normalized removal rate ranges from about 0.9 (line **36**C) to about 1.2 (line **36**B). The region of wafer ranging from 148 mm to 150 mm is not measured since this region of wafer does not generate complete dies.

FIG. **11**B illustrates similar results compared to FIG. **11**A, except that gap G**1** (FIG. **5**) is increased to 1.5 mm, while other test conditions remain the same as in FIG. **11**A. It is observed that by increasing gap G**1** (and also increasing the inner diameter of retaining ring), the non-uniformity in the removal rate becomes less severe. For example, the normalized removal rate is reduced to a range from about 0.95 (line **36**C) to about 1.1 (line **36**B). In addition, the non-uniform region of the sample wafer is now reduced to a range between about 140 mm and about 148 mm.

FIGS. **12**A and **12**B further illustrate the results obtained from silicon wafer samples, and the results demonstrate the effect of increasing the inner edge of retaining ring and extending membrane to contact the entire wafer top surface. The X-axis again represents the distance to the wafer center, and the Y-axis represents the normalized removal rate. Again, lines **38**A in FIGS. **12**A and **12**B are obtained by applying a reference pressure to polishing pad **14** through retaining ring **32** so that the removal rates in the inner region of the sample wafer are substantially uniform.

FIG. **12**A illustrates the results obtained when gap G**1** (FIG. **5**) is 0.5 mm, and membrane **26** extends to 149 mm, which is 1 mm away from the wafer edge. Line **38**B is obtained by increasing the pressure of retaining ring by 40 hpa relative to the reference pressure. Line **38**C is obtained by reducing the pressure of retaining ring by 40 hpa relative to the reference pressure. As illustrated, lines **38**B and **38**C in FIG. **12**A have the non-uniform region spanning from about 123 mm (to wafer center) to about 148 mm. The largest variation of the normalized removal rate ranges from about 0.8 (line **38**C) to about 1.3 (line **38**B).

FIG. **12**B illustrates similar results compared to FIG. **12**A, except that gap G**1** (FIG. **5**) is increased to 1.5 mm, and membrane extends to contact all the way to the wafer edge, while other test conditions remain the same as in FIG. **12**A. It is observed that the non-uniformity in FIG. **12**B is less severe compare to FIG. **12**A. For example, the highest span of the normalized uniformity ranges from about 0.95 (line **38**C) to about 1.1 (line **38**B). In addition, the non-uniform region now ranges from about 144 mm to about 148 mm. which is even smaller than the range of 140 mm to 148 mm in FIG. **11**B. Accordingly, FIGS. **12**A and **12**B reveal that increasing gap G**1** and expanding membrane to the wafer edge have a beneficial result to the uniformity in the removal rate.

The comparison of FIGS. **11**A, **11**B, **12**A, and **12**B reveals that expanding membrane to the wafer edge has beneficial results. This is against the conventional thinking that pressing the inner region **24**C (FIG. **10**) of wafer **24**, but not all the way to the edges of wafer **24**, would be enough since the outer region **24**B has no complete dies. However, the above-discussed results indicate that extending membrane to the entire wafer **24** has a significant beneficial effect on the whole wafer uniformity of the removal rate.

The embodiments of the present disclosure have some advantageous features. By forming multi-layer retaining ring having different hardness values, expanding membrane to the wafer edge, and/or increasing the inner diameter of the retaining ring, the uniformity of the removal rate of wafer is improved. In accordance with some embodiments of the present disclosure, these methods may be combined in any combination to further improve the uniformity of the removal rate.

In accordance with some embodiments of the present disclosure, an apparatus for performing chemical mechanical polishing on a wafer includes a polishing head that includes a retaining ring. The polishing head is configured to hold the wafer in the retaining ring. The retaining ring includes a first ring having a first hardness, and a second ring encircled by the first ring. The second ring has a second hardness smaller than the first hardness.

In accordance with alternative embodiments of the present disclosure, an apparatus for polishing a wafer includes a polishing head, which has a flexible membrane configured to be inflated and deflated. The flexible membrane is configured to press regions from a center to an edge of a planar top surface of the wafer when inflated.

In accordance with alternative embodiments of the present disclosure, an apparatus for polishing a wafer includes a polishing head, which includes a retaining ring. The polishing head is configured to hold the wafer in the retaining ring. The retaining ring includes a first ring having a first hardness, and a second ring encircled by the first ring. The second ring has a second hardness smaller than the first hardness. A flexible membrane is encircled by the retaining ring. The flexible membrane is configured to be inflated and deflated, and the flexible membrane is configured to press on a curved edge of the wafer when inflated.

The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

What is claimed is:

1. A method of forming a semiconductor wafer, the method comprising:
- placing a wafer in a polishing head, the polishing head comprising:
  - a flexible membrane comprising a plurality of zones, each of the zones including a chamber sealed by a material of the flexible membrane;
  - a plurality of air passages, each of the chambers being connected to one or more of the air passages; and
  - a retaining ring comprising:
    - a first ring having a first hardness;
    - a second ring within the first ring having a second hardness, wherein the second hardness is less than the first hardness by a difference greater than about 10 on Shore D scale, the second ring encircling the wafer in a plan view; and
    - a third ring surrounding the first ring having a third hardness, wherein the third hardness is greater than the second hardness by a difference greater than about 30 on Shore D scale, and wherein the first ring, the second ring, and the third ring are joined together to form the retaining ring; and
- polishing the wafer by bringing the wafer into contact with a polishing pad.

2. The method of claim **1**, wherein prior to polishing, a first bottom surface of the first ring is level with a second bottom surface of the second ring.

3. The method of claim **1**, wherein during polishing, a first height of the first ring is different than a second height of the second ring.

4. The method of claim **3**, wherein the first height is greater than the second height by a distance in a range between 0.01 mm and 3 mm.

5. The method of claim **1**, wherein the first hardness has Shore D hardness in a range between 80 and 90.

6. The method of claim **1**, wherein the third hardness is greater than the first hardness.

7. The method of claim **1**, wherein the wafer is brought into contact with the polishing pad by pumping air through the plurality of air passages to inflate the zones of the chamber.

8. A method of forming a semiconductor wafer, the method comprising:
- placing a wafer in a polishing head, the polishing head comprising:
  - a retaining ring comprising:
    - a first ring comprising polyphenylene sulfide (PPS) or polyetheretherketone (PEEK);
    - a second ring within the first ring, the second ring defining the wafer holding region to hold the wafer, the second ring having a second hardness less than a first hardness of the first ring, the

second ring comprising polyurethane, polyester, polyether, or polycarbonate; and

a third ring surrounding the first ring, the third ring having a third hardness greater than the first hardness and the third hardness is greater than the second hardness by more than 30 on a Shore D scale, wherein a first top surface of the first ring is level with a second top surface of the second ring and a third top surface of the third ring; and

a flexible membrane having a plurality of sealed chambers, the flexible membrane having a diameter less than a diameter of the wafer holding region; and

polishing the wafer by bringing the wafer into contact with a polishing pad.

9. The method of claim **8**, wherein, during polishing, the second ring contacts the polishing pad and the polishing pad protrudes adjacent the second ring.

10. The method of claim **9**, wherein, during polishing, the polishing pad recesses below the wafer, thereby forming a void under the wafer.

11. The method of claim **8**, wherein the first ring extends into the polishing pad by a greater amount than the second ring during polishing.

12. The method of claim **8**, wherein the polishing pad between the second ring and the wafer protrudes above a bottom surface of the second ring during polishing.

13. The method of claim **8**, wherein a force on the polishing pad under an edge of the wafer is less than a force on the polishing pad under a center region of the wafer during polishing.

14. The method of claim **8**, wherein a first bottom surface of the first ring is coplanar with a second bottom surface of the second ring prior to polishing.

15. The method of claim **8**, wherein a sidewall of the second ring is separated from the wafer by a gap of greater than 1 mm.

16. A method of forming a semiconductor wafer, the method comprising:

placing a wafer in a retaining ring of a polishing head, the retaining ring comprising three or more concentric sub-rings, wherein a difference in Shore D hardness between adjacent sub-rings is greater than 5, and wherein the adjacent sub-rings are joined, wherein the polishing head comprises a flexible membrane comprising a plurality of zones, the zones being concentric and having circular shapes, wherein a difference in Shore D hardness between an outermost sub-ring of the retaining ring and an innermost sub-ring of the retaining ring is greater than 30; and

polishing the wafer by bringing the wafer into contact with a polishing pad.

17. The method of claim **16**, wherein polishing comprises contacting each of the three or more concentric sub-rings to the polishing pad, wherein the innermost sub-ring of the three or more concentric sub-rings protrudes into the polishing pad less than an outer sub-ring of the three of more concentric sub-rings.

18. The method of claim **17**, wherein a sidewall of the innermost sub-ring is spaced apart from a sidewall of the wafer by a gap of greater than 1 mm.

19. The method of claim **18**, wherein an upper surface of the innermost sub-ring is level with an upper surface of the outer sub-ring.

20. The method of claim **16**, wherein polishing comprises pressuring a first zone of the plurality of zones to a different pressure than a second zone of the plurality of zones.

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